Pump Less Wearable Microfluidic Device for Real Time pH Sweat Monitoring

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Abstract

This paper presents the fabrication and the performance of a novel, wearable, robust, flexible and disposable microfluidic device which incorporates micro-Light Emitting Diodes (μ-LEDs) as a detection system, for monitoring in real time mode the pH of the sweat generated during an exercise period. Up to now sweat analysis has been carried out using awkward methods of collecting sweat followed by laboratory analysis. The approach presented here can provide immediate feedback regarding sweat composition to an athlete and coach. The great advantage of sweat analysis is the fact that it is a completely non-invasive means of analyzing the wearer's physiological state and ensuring their health and well-being.

Keywords: microfluidic; pH; sport science; sweat monitoring; wearable sensors

1. Introduction

Nowadays, Micro-Total-Analysis-Systems and Lab-on-a-Chip technology are widely used in analytical chemistry and biotechnology [1] but it still is rarely used in other areas like sports science. In this field, wearable sensors are are becoming increasingly employed, through the use of embedded transducers or smart fabrics for monitoring parameters like breathing rate, heart rate and footfall [2]. However, due to their relative complexity, there is very little activity in the development of real-time wearable chemo/bio sensing for sports applications. In contrast to transducers, wearable chemo-/bio-sensing requires that the desired sample of analysis, usually a body fluid such as sweat, is delivered to the sensor's active surface whereon a reaction happens and a signal is generated. Moreover the system must be low cost, while still being robust, miniature, flexible, washable, reusable or disposable [3]. All these requirements point to microfluidic devices as the key tools for improving wearable chemo-/bio-sensing. In our laboratories, as part of Biotex EU-funded project (see www.biotex-eu.com/), a wearable, wireless sweat analysis system was successfully fabricated and tested for monitoring sports performance and training [4,5]. The sensors were integrated into a wearable platform that allowed direct collection of sweat in an unobtrusive way. A textile-based fluidic system used a combination of moisture wicking fabrics and superabsorbent materials to collect and deliver sweat. Fig.1(a) shows the fabric fluidic channel with a pH sensitive dye (bromocresol purple) integrated in the channel. The colorimetric response of the dye was detected using LEDs integrated into the device cover, shown in Fig.1(b).

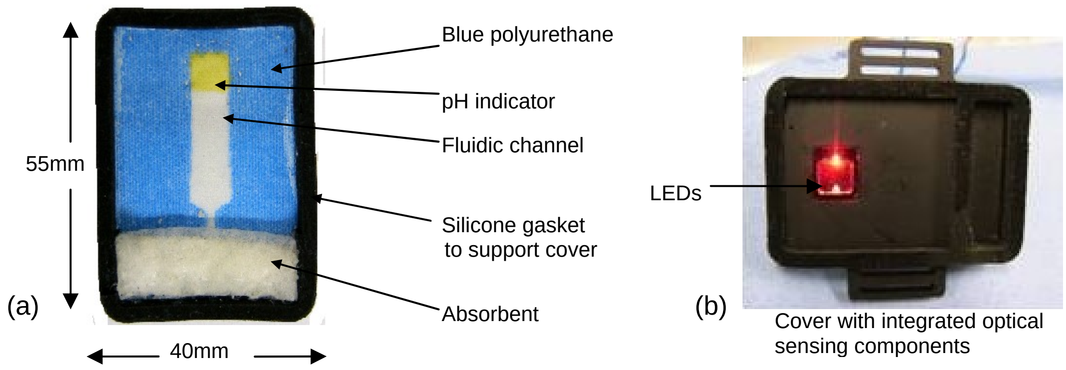


Fig. 1 Fabric-based sweat analysis system, developed as part of the BIOTEX project

Here, we show further progress in the miniaturisation of the system by generating an autonomous microfluidic device capable of measuring on-line pH changes. This further reduction in the physical scale of the system means that smaller quantities of sweat are needed for analysis, which makes the device suitable for users with low sweat rate, and simultaneously improves the system response time.

2. Microfluidic device fabrication

Fig.2 (a) is a schematic representation of the fabrication of the microchip structure and Fig.2 (b) presents a picture of the final microchip. The microchip (2 x 3cm) is easily fabricated using poly(methyl-methacrylate) and pressure-sensitive adhesive in three layers using a CO_2 ablation laser. The inlet has a drop shape for efficient sweat collection when in contact with the skin. The sensing area is a small patch of 1 mm length with a pH sensitive dye, which varies in colour depending on the acid/base nature of the sweat moving along the microfluidic channel. Since human sweat generally lies in the region of pH 5-7, bromocresol purple has been chosen as it shows a colour change from yellow to blue over this pH range. The sweat is drawn into the sensing area by an absorbent fiber placed at the end of the channel.

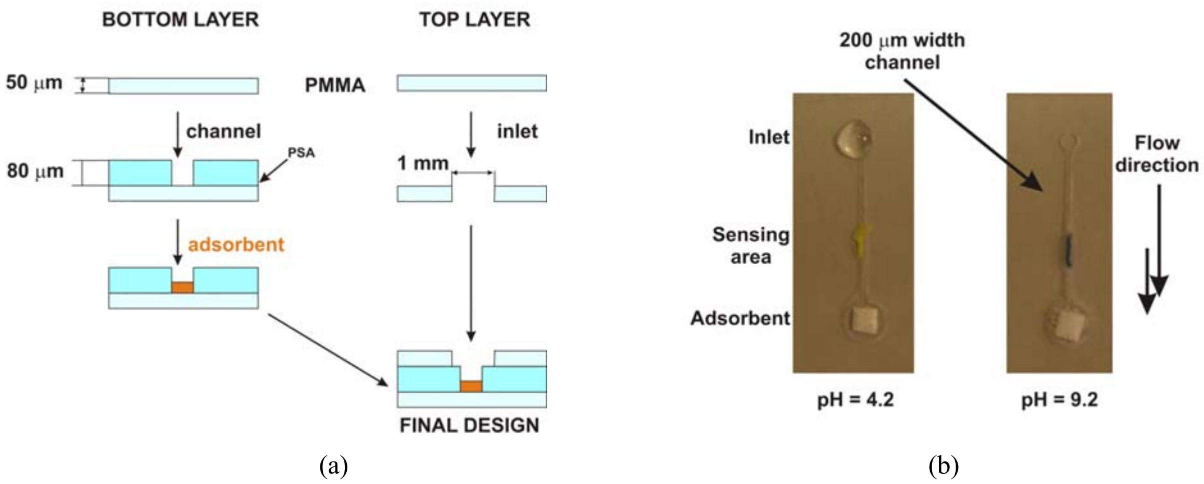
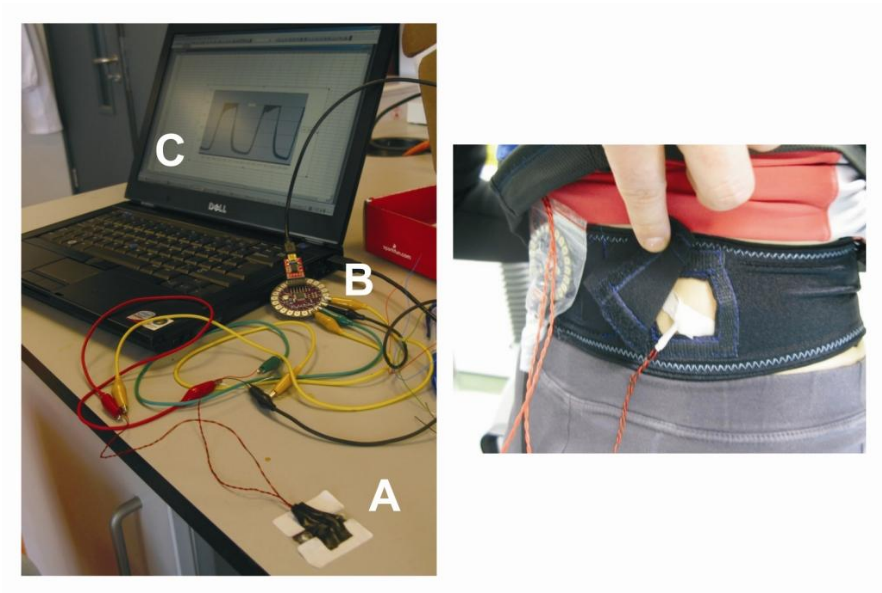


Fig. 2. (a) Schematic representation of the microchip fabrication; (b) Picture of the microchip at pH: 4.2 and pH: 9.2.

3. Detection system

The detection takes place by means of two μ-LEDs placed above and below the sensing area. Black masking tape is used to position the μ-LEDs to block ambient light; one of the μ-LEDs acts as light source while the other is reverse biased and acts as a detector [6]. The detected light intensity is related to the discharge time due to stray capacitance of the device. Both μ-LEDs are controlled by a microcontroller (Lilypad Arduino) which is designed for wearable applications as it has pins that can be stitched to using conductive threads. The data is sampled at 2Hz and transferred to a laptop by an RS232 serial link. This link could be easily replaced by a wireless connection by attaching a Bluetooth® modem (BlueSMiRF silver) to the Arduino microcontroller. This modem works as a serial (RX/TX) pipe. A serial stream at baud rate of 9600bps can be passed seamlessly to a laptop up to 30m away. The experimental set-up used for pH measurements is shown in Fig.3 (a). Fig.3 (b) shows the microfluidic device in contact with the skin before exercise performance. The microfluidic device is protected from the external influence, like light, by a velcro belt.



(a) (b)

Fig. 3. (a) Set-up. A) Microchip and μ-LEDs system in a simple adhesive plaster. B) Arduino Lilypad microcontoller C) Data transferred from microcontroller to laptop using serial connection.(b) Microfluidic device in contact with the skin protected by a velcro belt.

4. Performance of the microfluidic device

Fig.4 shows two different pH measurements using the same microfluidic device. The light intensity varies from 2000 counts when the pH is higher than 7 (blue) down to 250 counts when pH is below 5 (yellow). These results are reproducible, suggesting that the device can be used for on-line monitoring of sweat during sport performance and training. Moreover, the device is very small, portable and robust, can be adjusted as a wireless system and it is easily incorporated into a simple adhesive plaster which will cause no discomfort during training.

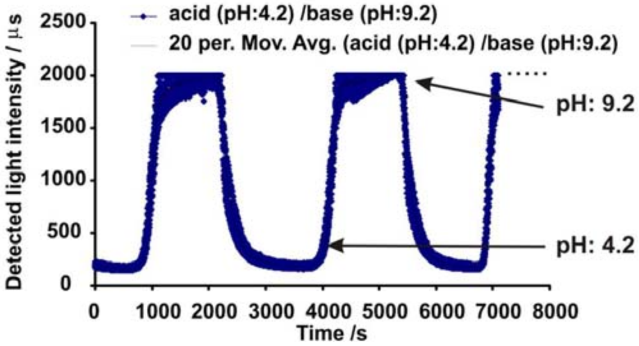


Fig. 4. pH response of the sensing area of the microfluidic device.

5. Conclusion

We have showed here the fabrication of a novel, wearable, robust, flexible and disposable microfluidic device. The system incorporates micro-Light Emitting Diodes (µ-LEDs) as a low-cost and low-power detection system.

The device was shown to respond over the pH range typically encountered in exercise sessions, implying that it could be employed for real-time monitoring of sweat pH. Moreover, the device is flexible and comfortable to wear providing an unobtrusive and non-invasive method for the analysis of sweat during exercise.

Acknowledgements

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